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Applicant(s): MARCONI CO LTD ;

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ABSTRACT:

A self-focussing phased-array antenna system for use with a combined intelligence signal (5) and pilot- signal (P) which may lie in the signal band. Each element (1, 3, 5, etc.) of the array has a phase-locked loop (21) which produces a signal (theta s- theta v) having a fixed offset from the pilot/intelligence difference in both phase and frequency. Automatic pilot-phase compensation is thereby achieved both in poor S/N situations and for pilot frequencies within the signal band.

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Selected US specifications from IPC sub-class H01Q

(54) **Phased array antenna system**

(57) A self-focussing phased-array antenna system for use with a combined intelligence signal (5) and pilot-signal (P) which may lie in the signal band. Each element (1, 3, 5, etc.) of the array has a phase-locked loop (21) which produces a signal $(\theta_s-\theta_v)$ having a fixed offset from the pilot/intelligence difference in both phase and frequency. Automatic pilot-phase compensation is thereby achieved both in poor S/N situations and for pilot frequencies within the signal band.

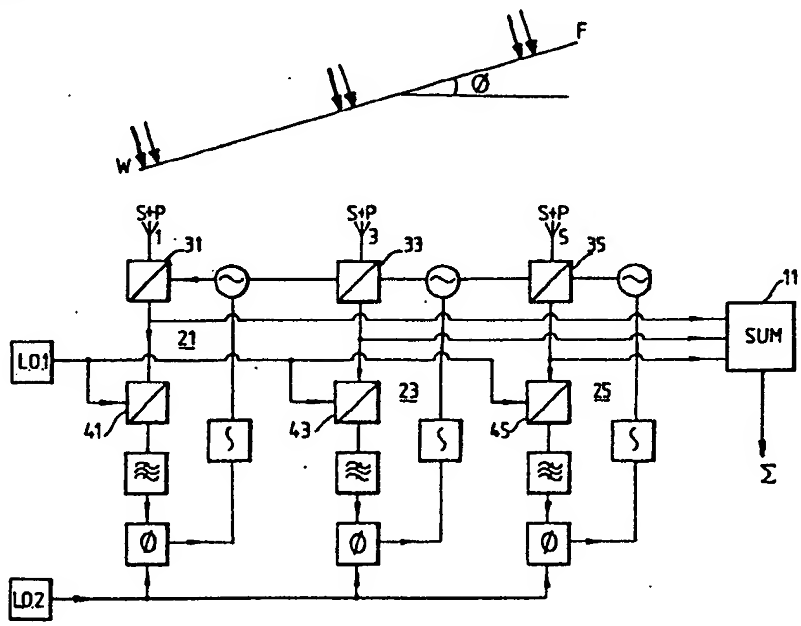

Fig. 1

The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.

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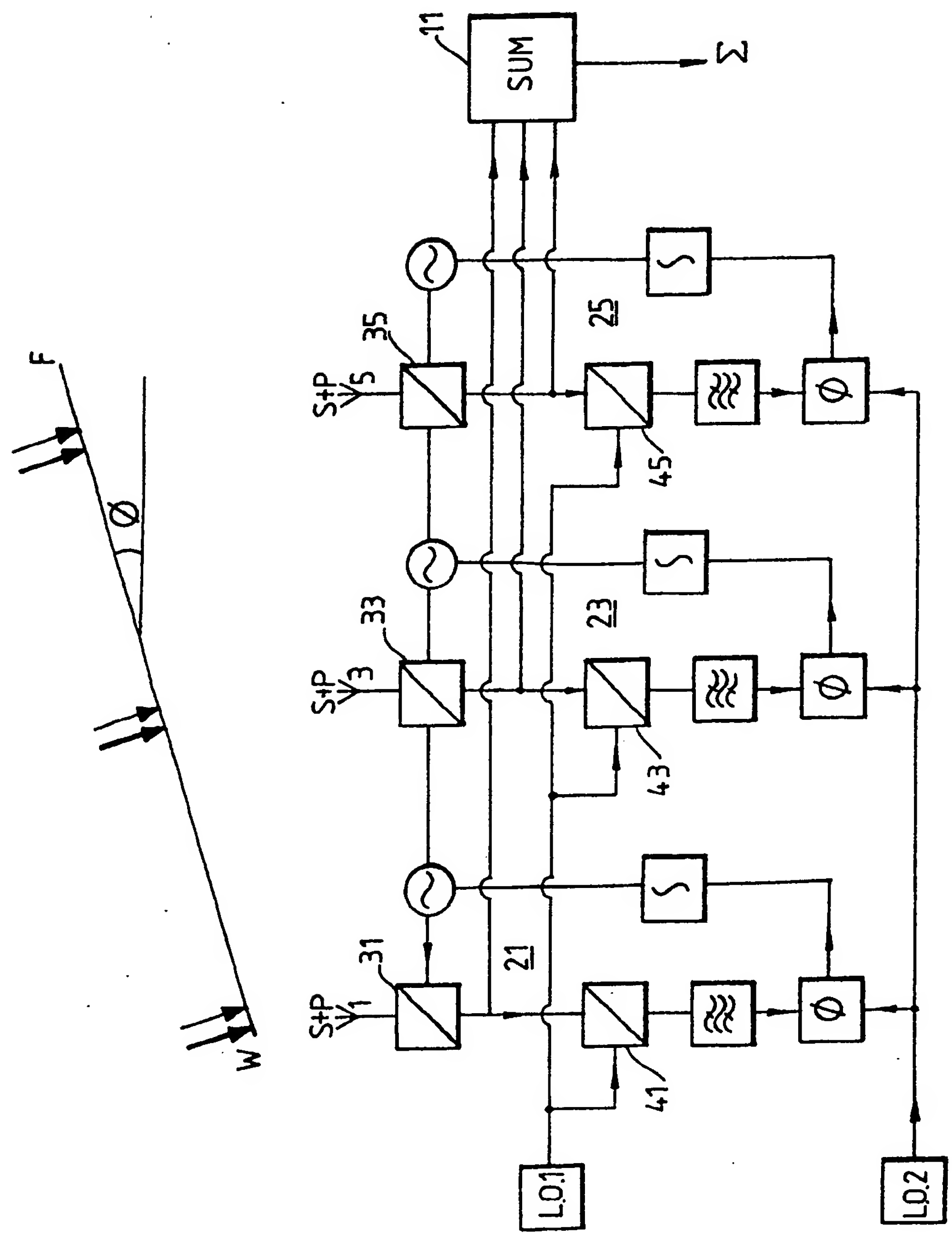

Fig. 1

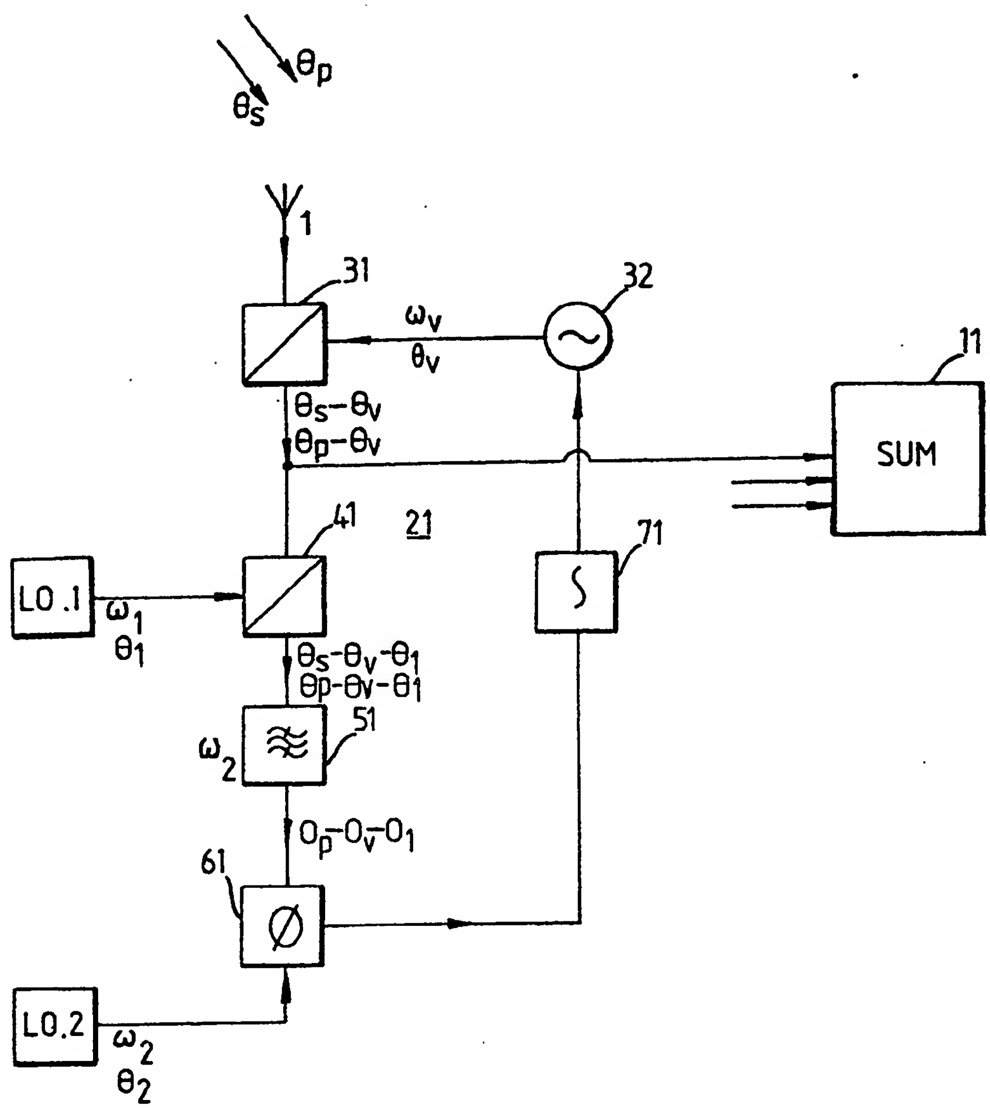
θp
θs
1
31
32
ωv
θv
11
SUM
θs−θv
θp−θv
41
21
71
LO.1
ω1
θ1
θs-θv-θ1
θp-θv-θ1
ω2
51
θp−θv−θ1
61
Ø
LO.2
ω2
θ2

Fig. 2

SPECIFICATION

Phased array antenna system

This invention relates to phased array antenna systems. In such systems it is well known to steer the response characteristic of the array, i.e., the 'beam' so called, by including in each antenna element feed a progressively increasing phase shift so that the sum of the element signals is a maximum (i.e., the output signals are all in phase) for a signal source direction at an angle offset from the physical array forward direction. Control of the phase increment from element to element provides control of the offset angle.

In a development of this basic system, automatic lock on to the received signal is achieved by inserting a controllable phase shifter in all but one element of the array, comparing the phases of the shifted and unshifted signals and controlling the phase shifters until the output phases are equal. The 'beam' will then track the signal source. Such a system is known as a "self-phasing" or "self-focussing" array (even though no true focussing is involved).

Summation of the phase compensated output signals can be achieved at an intermediate frequency if a local oscillator signal is applied to a frequency changer in each antenna feed and the phase shift incorporated in the individual local oscillator signal.

In certain situations, particularly in the field of satellite communications, a pilot signal of narrow bandwidth and of frequency close to the communications signal band is transmitted with the intelligence signal and it is known to use this pilot signal at the receiver in place of a local oscillator signal. The advantage of this device is that an inherent phase shift is built in to the pilot signal, graded by, and thus exactly in accordance with, the distance for which compensation is required at each element. Exact *phase* compensation requires the pilot wavelength to be equal to the signal wavelength but this is normally considered impractical (since it results in zero or near zero intermediate frequency). Consequently, the pilot frequency is maintained close to, but outside the signal band.

Previous schemes for achieving this phasing have involved separately filtering out the pilot and signal frequencies and applying them to a mixer. Although satisfactory as a theoretical concept for laboratory experiment there ar some important practical limitations. Thus the pilot bandwidth must be narrow in order to avoid a large degradation in S/N ratio. This implies the use of a high Q filter and conflicts with other requirements, such as allowance for Doppler shifts and pilot oscillator fr quency stability. Again, if the pilot transmission lies within the signal band it will be difficult for the array to work over the entire band, since the convertor output frequency is equal to th difference frequency and overlap would make direct coverage of the entire band virtually impossible.

An object of the invention is therefore to provide a self-focussing phased-array antenna system which can operate in conditions of poor signal/noise ratio and with a pilot transmission which may be within the signal band.

According to one aspect of the present invention, an antenna system comprising a phased array of antenna elements providing beam steering responsive to the source direction of a received signal which comprises a signal band and a pilot signal, is characterised in that, in respect of each antenna element, a phase-locked loop is arranged to provide a phase-controlled signal of phase locked to the pilot signal for differencing with the received signal to provide a phase compensated output signal of relatively low frequency, the phase-controlled signal being responsive to a phase comparison of a frequency offset version of the said output signal and a local oscillator signal common to all of the phase-locked loops, the arrangement being such that the output signals are of the same phase such as to produce a maximum value on summation irrespective of the direction of the source of the received signal.

According to another aspect of the invention an antenna system comprising a phased array of antenna elements providing beam steering in response to a received signal comprising a signal band and a pilot signal, is characterised by a signal path from each element of the array to common summing means, each such path including first frequency changing means which forms part of a respective phase-locked loop, the phase-locked loop comprising, in sequence, the first frequency changing means, further frequency changing means, a band-pass filter, a phase-comparator arranged to compare the phase of the filter output with the phase of a local oscillator signal common to all of said phase-locked loops, and an integrator responsive to the output of the phase-comparator to control a voltage-controlled-oscillator which provides a differencing signal to the first frequency changing means, and the arrangement being such that in operation the voltage-controlled oscillator signal is locked in phase to the pilot signal and the output signal from the first frequency changing means is offset in frequency from the diff rence betwe n the signal band frequency and the pilot frequency.

According to a feature of the invention, the phase-controlled signal may be mix d with a relatively high frequency local oscillator signal common to all of the phase-locked loops to provide a transmit signal which tracks the source of the received signal.

A self-focussing phased-array antenna sys-

tem will now be described, by way of example, with reference to the accompanying drawings, of which:

Figure 1 is a circuit diagram of the antenna system; and Figure 2 is a diagram of one module of the circuit of Figure 1 in respect of a particular antenna element.

The system will be described in relation to a satellite transmission to a ship or aircraft, the transmission comprising a signal band having a bandwidth of perhaps 10 MHz at a frequency of, say, 1500 MHz, and an accompanying pilot signal assumed to have a frequency within the signal band but in a very narrow 'slot' exclusive to the pilot signal.

Referring to Figure 1, the system comprises a plurality of perhaps ten antenna elements 1, 3, 5 etc., only three being shown, for simplicity. It is assumed that these are arranged in a linear array, although this is by no means essential. A wavefront WF is received by the array from a source, the satellite, which wavefront is offset by an angle ϕ from the wavefront that a boresight signal would present. It is rquired to provide an output signal from summing means 11 which is the sum of the individual element signals that would obtain if ϕ were zero, i.e., if the array were directed at the source.

The signal path between each element 1, 3, 5 etc., and the summing means 11 includes a respective frequency changer, a mixer 31, 33, 35, which is part of a phase-locked loop module 21, 23, 25 etc. Each phase-locked loop includes a further mixer 41, 43, 45 which is fed by a common local oscillator LO1, the frequency of which is typically in the range 10 MHz—100 MHz. A second local oscillator LO2 also common to all of the phase-locked loops provides a low frequency signal, typically in the range 5 kHz—50 kHz for phase comparison purposes, as will be explained.

Referring now to Figure 2 this shows one of the antenna element modules (21).

Both intelligence signal S and pilot signal P are received at the antenna element 1, having phases θ_s and θ_p. Both signals are applied to the mixer 31 which also receives a signal of frequency ω_v and phase θ_v from a voltage controlled oscillator 32. The difference signal output is at a relatively low frequency compared to that of the received signal frequency and it is this signal which contributes to the final output signal in the summing circuit 11.

The VCO 32 derives its controlling input from a phase-sensitive detector 61 by way of an integrator 71. The PSD 61 derives one input from the common local oscillator LO2 at a frequency ω_2 and phase θ_2. Its other input, which, in the locked loop condition is driven by the loop into synchronism with the LO2 signal, is derived from a filter 51 having a narrow passband at ω_2, the LO2 frequency. The input to the filter 51 comprises two signals, a twice shifted version of the intelligence signal P, having a phase $\theta_p - \theta_v - \theta_1$, and a twice shifted version of the pilot signal S, having a phase $\theta_s - \theta_v - \theta_1$. The second shift on each of these two signals is provided by the common local oscillator LO1, having a frequency and phase $\omega 1$ and θ_1, by way of a mixer 41.

Whereas the difference between the signal and pilot frequencies can become zero it may be seen that the output of the mixer 31, and thus the output of the module, cannot be closer to zero than the local oscillator LO1 frequency, ω_1, the output of mixer 31 being mixed with the local oscillator LO1 signal to produce a frequency which is locked to the very low frequency of local oscillator LO2.

The mixer 41 to which LO1 is applied, provides image rejection in order to avoid incurring a noise penalty. Its ouput is filtered by filter 51 having a passband at ω_2, the frequency of the local oscillator LO2, of the order of 5 kHz—50 kHz. The filter output and the LO2 signal are compared in the phase-sensitive detector 61 which produces a d.c. output of magnitude and sense varying with the relative phase of the two signals.

When the loop is in lock a zero output from the phase-sensitive detector 61 will result in a constant output from the integrator 71 and a signal of constant frequency (ω_v) and constant phase (θ_v) from the VCO 32.

In the locked loop condition, there are two difference outputs from the mixer 31, of phases $\theta_s - \theta_v$ and $\theta_p - \theta_v$. The corresponding outputs from mixer 41 have phases $\theta_s - \theta_v - \theta_1$ and $\theta_p - \theta_v - \theta_1$. The tuning range of the loop is such that the pilot signal component of these two is selected by the bandpass filter 51 for phase balancing against the local oscillator LO2.

The controlled phase θ_v is therefore determined so that:

$$\theta_p - \theta_v - \theta_1 = \theta_2$$

i.e. $\theta_v = \theta_p - \theta_1 - \theta_2$

The output of the module, which is passed to the summing circuit 11 has a phase $\theta_s - \theta_v$ which is thus equal to $\theta_s - \theta_p + \theta_1 + \theta_2$. If the signal frequency and the pilot frequency are fairly close, say within about 5% of each other, then $\theta_s - \theta_p$ will be approximately the same at all antenna elements and the outputs will have th same phase and consequently sum to a maximum.

The invention provides a m dular system which considerably simplifies beam control since each antenna element module, as shown in Figure 2, can be of identical construction requiring no central control hardware.

The invention also enables self-phasing to be implemented in conditions of poor signaljnoise ratio with a pilot transmission adjac nt to or within the signal band. The low

frequencies input to th phase comparator mean that n high-Q filter is involved. In addition there are no significant Doppler limitations.

It will be appreciated that, having determined the respectivephase (θ_v) of the VCO signal for each individual antenna element, a transmitted signal can be produced by mixing this VCO signal with a local oscillator signal common to all of the modules and higher in frequency than the VCO signal. The resulting signal will then be phased so as to track the source of the received signal, i.e. to return to the satellite.

CLAIMS

1. An antenna system comprising a phased array of antenna elements providing beam steering responsive to the source direction of a received signal comprising a signal band and a pilot signal, the system comprising, in respect of each antenna element, a phase-locked loop arranged to provide a phase-controlled signal of phase locked to said pilot signal for differencing with the received signal to provide a phase compensated output signal of relatively low frequency, said phase-controlled signal being responsive to a phase comparison of a frequency offset version of said output signal and a local oscillator signal common to all of the phase-locked loops, the arrangement being such that the output signals are of the same phase such as to produce a maximum value on summation irrespective of the direction of the source of the received signal.

2. An antenna system comprising a phased array of antenna elements providing beam steering in response to a received signal comprising a signal band and a pilot signal, the system comprising a signal path from each element of the array to common summing means, each said path including first frequency changing means which forms part of a respective phase-locked loop, the phase-locked loop comprising, in sequence, the first frequency changing means, further frequency changing means, a band-pass filter, a phase-comparator arranged to compare the phase of the filter output with the phase of a local oscillator signal common to all of said phase-locked loops, an integrator responsive to the output of the phase-comparator to control a voltage-controlled-oscillator which is adapted to provide a differencing signal to said first frequency changing means, th arrangement being such that in operation the voltage-controlled oscillator signal is locked in phase to the pilot signal and the output signal from said first frequency changing means is offset in frequency from the difference between the signal band frequency and the pilot frequency.

3. An antenna system according to Claim 1 or Claim 2, wherein the pilot frequency lies within the said signal band.

4. An antenna system according to Claim 1 or Claim 3 as appendent to Claim 1, wherein said phase-controlled signal is mixed with a relatively high frequency local oscillator signal common to all of said phase-locked loops to provide a transmit signal which tracks the source of said received signal.

5. An antenna system substantially as hereinbefore described with reference to the accompanying drawings.

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